Supersonic Particle Deposition for Repair and Corrosion Protection of Mg Gearboxes

ASETSDefense Work Shop
Sept. 2, 2009

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Before

After

Report Documentation Page

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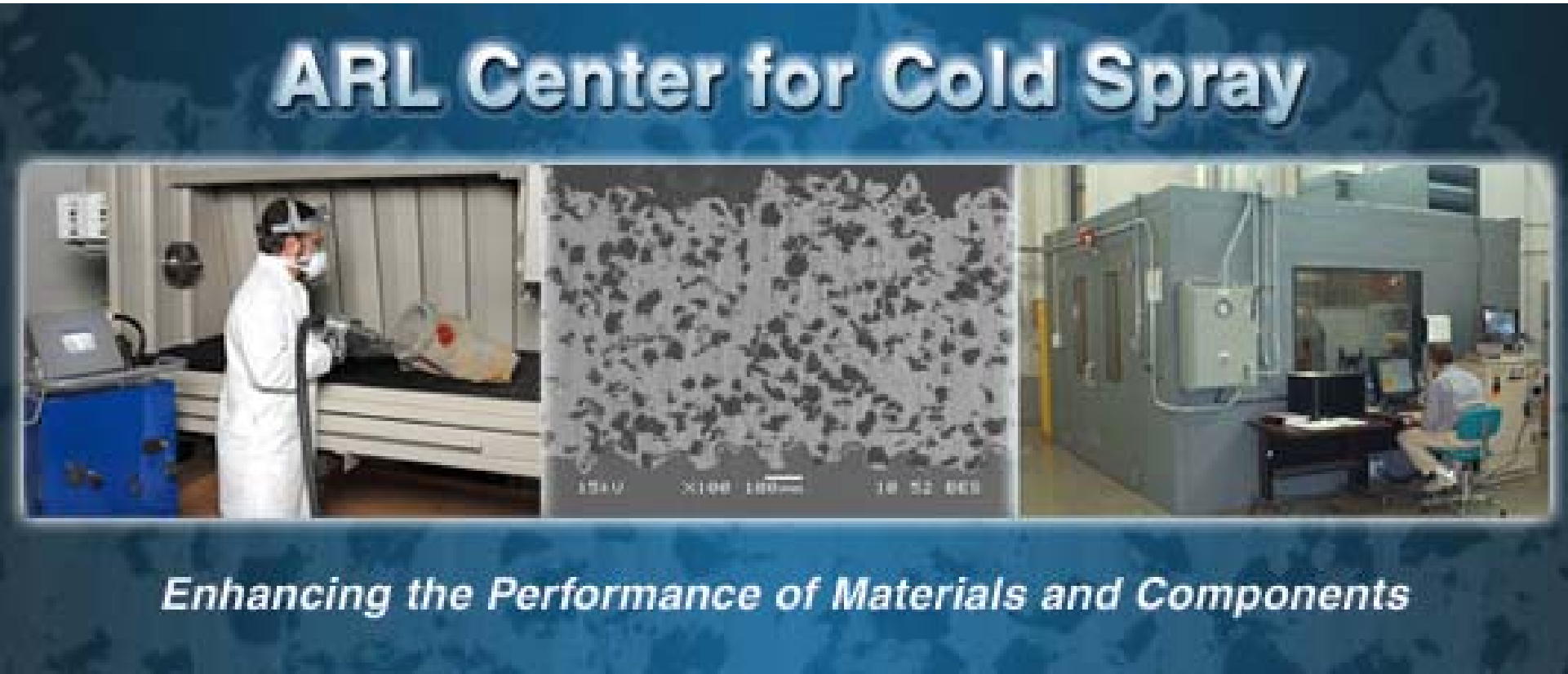
ARL Center for Cold Spray Team

TECHNICAL OBJECTIVES

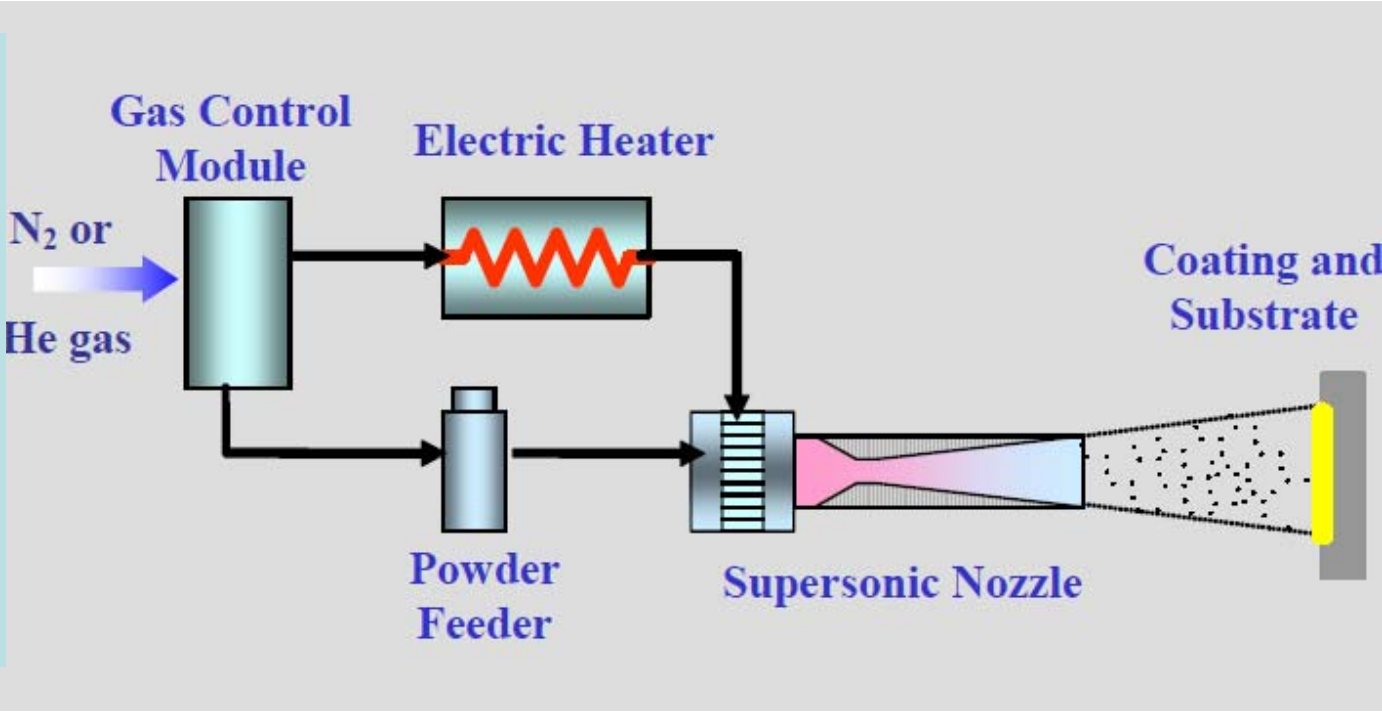
- Demonstrate and qualify SPD aluminum alloy coatings as a cost-effective, ESOH-acceptable technology to provide surface protection and a repair/rebuild methodology for Mg alloy components on Army and Navy helicopters and advanced fixed-wing aircraft such as the Joint Strike Fighter



Cold Spray/SPD Process

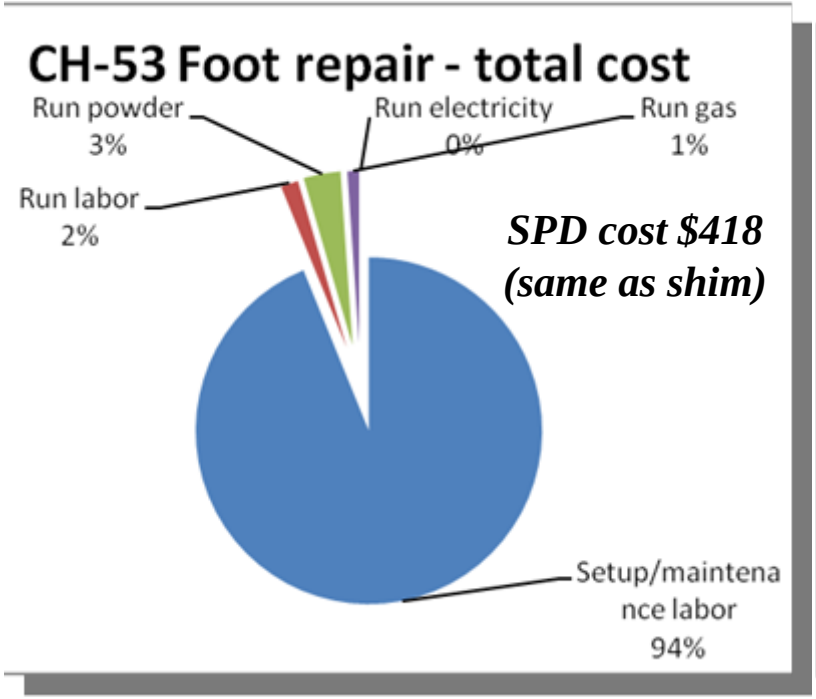
Cold spray, involves the introduction of a heated high-pressure gas such as He or N_2 together with 1 to 50 µm diameter particles of a metal, ceramic and/or polymer into a gun fitted with a De Laval rocket nozzle designed such that the particles exit at supersonic velocities ranging from 400 to 1500 meters-per-second and consolidate upon impacting a suitable surface to form a coating or free-standing structure.

- ***Gas temperature range from R.T. to 800°C***
- ***No melting of particles***
- ***Negligible oxidation***
- ***No decomposition or phase changes of deposited particles***

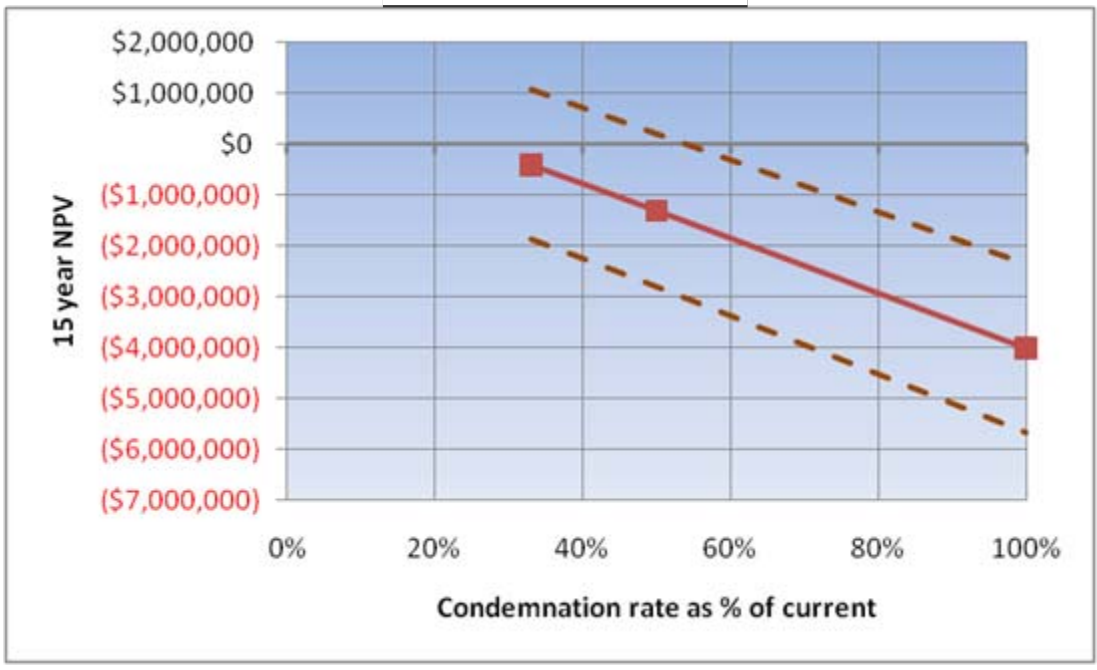


SPD Depot overhaul
CH-53 gearboxes

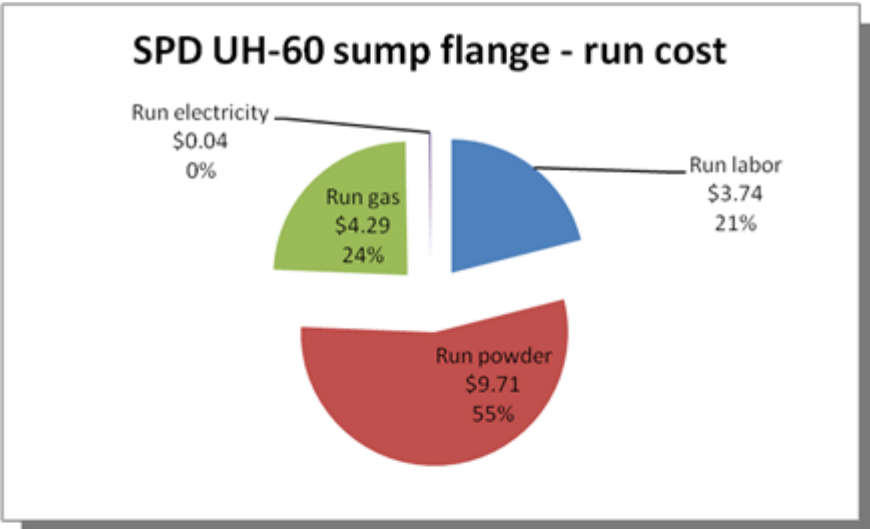
- ***SPD has little or no impact on repair cost***
- ***Most of cost is setup – actual process cost is small (same as glue shims)***
- ***Payback of capital and implementation cost is15 yrs with CH-53 only***
  - ***Depends on performance – reduced repair or condemnation***
  - ***Faster payback over all FRC workload***

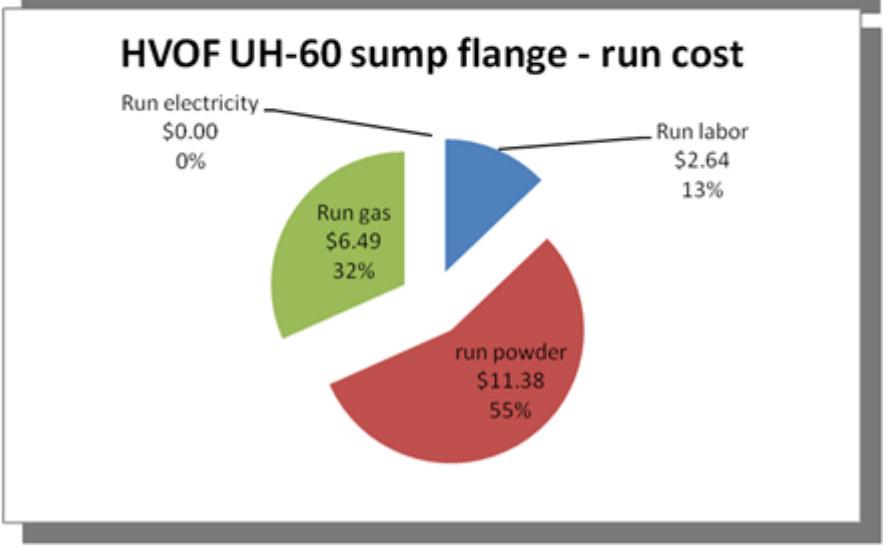


CH-53 only ±2σ



UH-60 sump flange repair



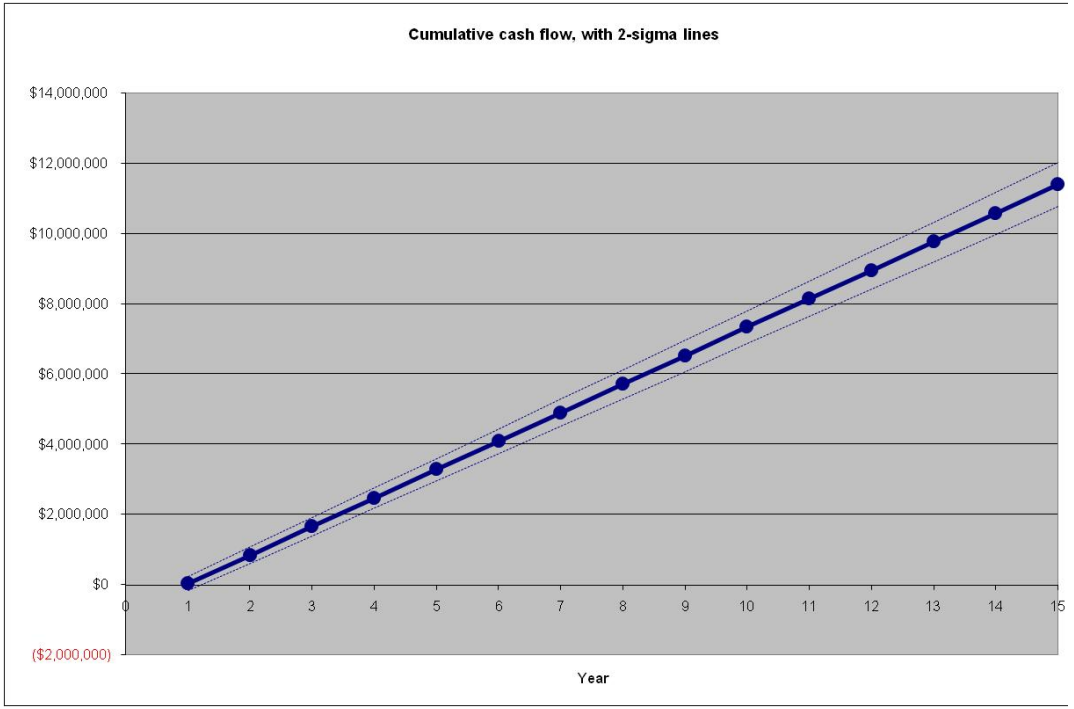


	SPD	HVOF
Setup/maintenance labor	$392.50	$392.50
Run labor	$3.74	$2.64
Run powder	$9.71	$11.38
Run gas	$4.29	$6.49
Run electricity	$0.04	$0.00
Total cost	$410.28	$413.01
Run cost	$17.78	$20.51

No cost impact (both processes vendor-supplied)

UH-60 Sump Flange Repair

- ***Problem is that HVOF does not really work***
  - ***Therefore SPD saves condemnation***
- ***85 gearboxes/year***
  - ***$11k ea to replace***
  - ***$1k ea to repair***
- ***Cost analysis includes equipment installation and adoption cost***
- ***Larger cost savings with more expensive gearbox housings***



	-2 sigma	Value	+2 sigma
15 yr NPV	$8,682,158	$9,229,033	$9,775,908
IRR	145%	111%	91%
ROI	82%	111%	140%
Payback period	1.2	0.0	0.0

Sump Cost Recovery

UH-60 Sump Assembly Main Module-Main Gearbox Repair

Substrates:
ZE41A & AZ91C Magnesium
Coating Material:
CP-Aluminum and/or 6061 Al

Part Numbers:
70351-48141-041
70351-08141-047

- ***Cost of new component $11,000.00 DLA (Defense Logistics Agency)***
- ***85 sumps need repair per year based on a Sikorsky study over the last 3 years***
- ***Total Replacement Cost Savings estimated to be $935,000.00/year***

Coatings and Substrates

Substrate Materials

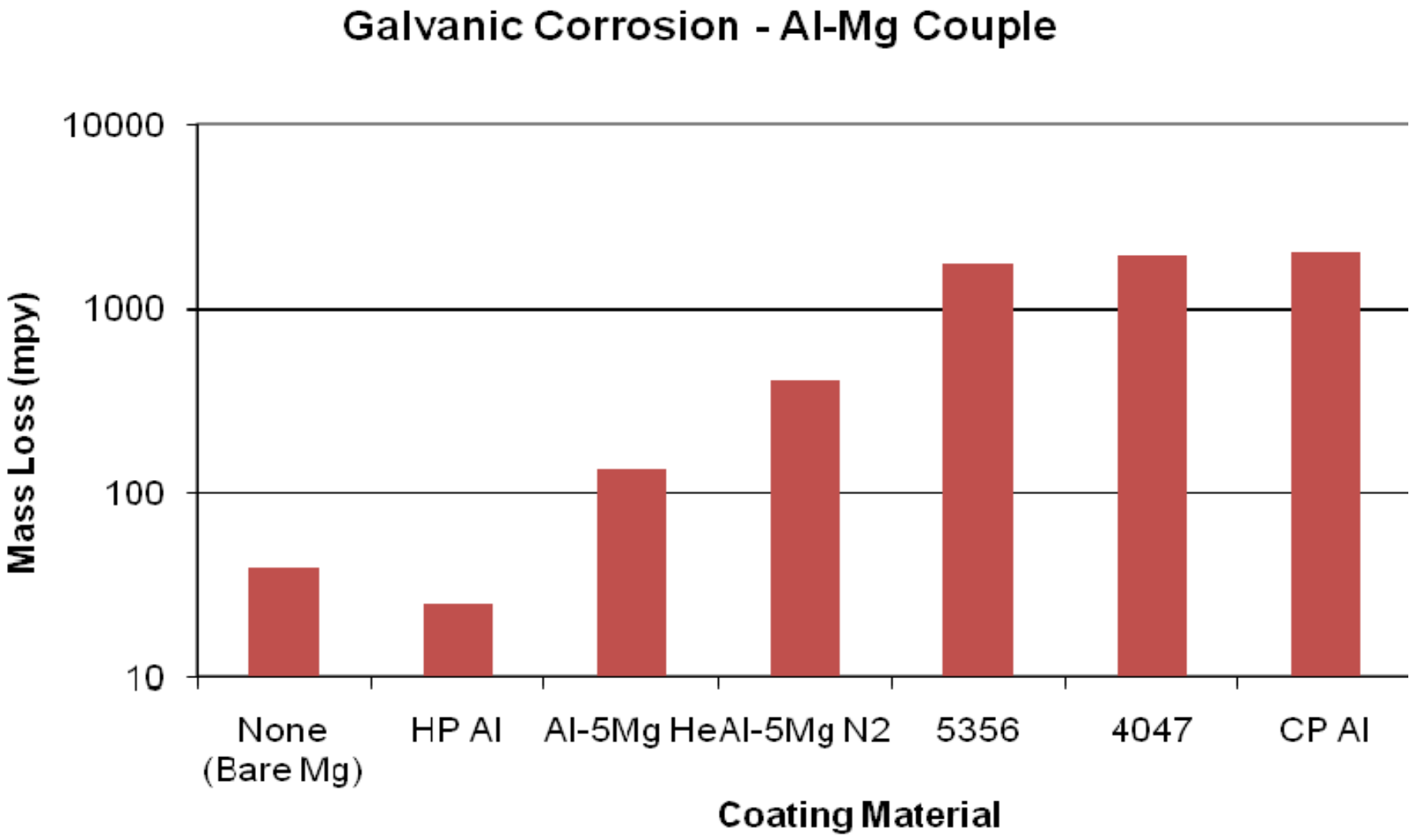
Material	Heat Treat (tens. strength)	Notes
AZ91C-T6	34 ksi	Legacy systems
ZE41A-T5	29 ksi	Legacy systems
EV31-T6	36 ksi	New CH-53, AAAV

RR Moore with 6061 SPD Coating

Candidate Coating Materials

- Commercially Pure Al- Hardness similar to ZE41A (60 to 70 VHN), Good general corrosion resistance. Candidate for non-structural coatings
- High Purity Al- Best Galvanic compatibility with Mg alloys but at a cost of lower hardness (50 VHN)
- 6061 aluminum alloy: 90 to 110 VHN, good general corrosion resistance, future candidate for more structural or load bearing coatings.

Galvanic Corrosion



Cathode slightly larger than anode

TECHNICAL APPROACH

Full JTP Qualification Plan

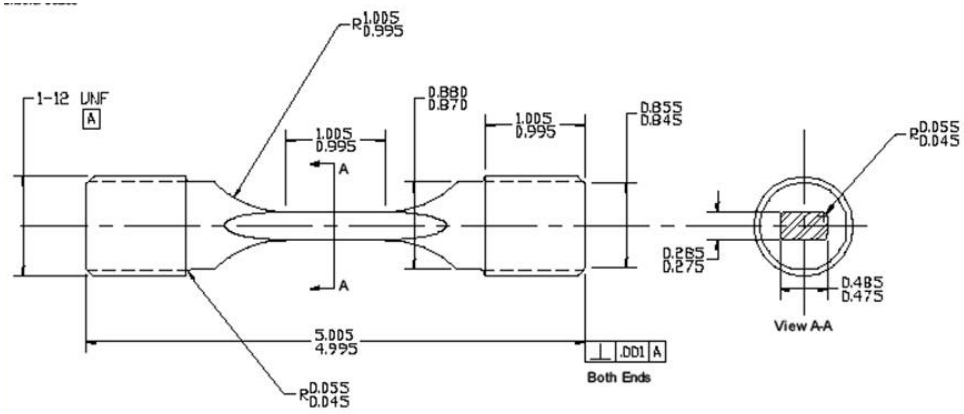
Mechanical Tests

- Adhesion Tensile Bond Test (ASTM C633)
- Almen Strips
- Flat Tensile Specimens
- R.R. Moore RB Fatigue
  - surface finished 125RA
- Fretting Fatigue – UTRC
- Impact - ASTM D5420
- Hardness
- Porosity
- ROSAN Insert Test
- Triple Lug Shear

1. **6061 Aluminum Alloy (He carrier gas)**
2. **HP-Al Bond Coat/CP-Al (N_2 carrier gas)**

Corrosion Tests

- **Un-scribed ASTM B117**
- **Scribed ASTM B117**
- **GM9540 Scribed**
- **Galvanic Corrosion (G71)**
- **Crevice Corrosion (G78)**
- **Beach Corrosion**
- **G85 Annex 4-SO_2**



UTRC Fretting Fatigue Specimen

Sump Repair Qualification Plan

Substrates: ZE41A & AZ91C Magnesium Alloys

Coating Material:

1.1. 6061 Aluminum Alloy (He carrier gas)

2.HP-Al Bond Coat/CP-Al (N_2 carrier gas)

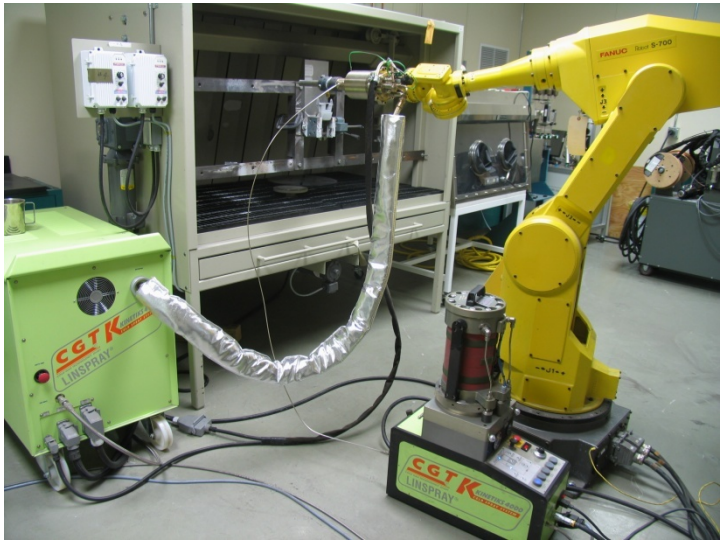
- Porosity < 1%
- Almen Strips
- Adhesion Tensile Bond Strength Test
- Unscribed ASTM B117 Salt Spray Test
- Scribed ASTM B117 Salt Spray Test
- G85 SO_2
- Beach Corrosion
- Hardness –(Pre/Post 385F-6hrs)
- Machining Evaluation Coupons(1/2 coated) & ½” diameter rods (2”of 6” length)

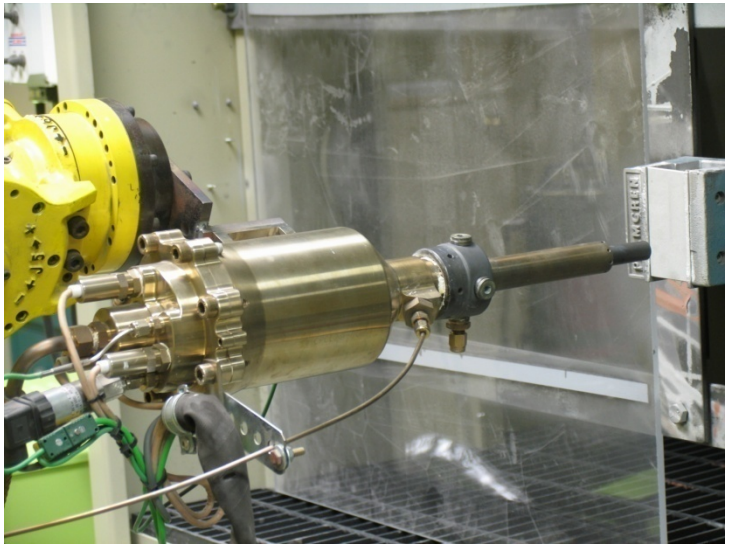
Timeline

- Over 550 Coated Samples (JTP and Sump Qualification)
  - 6061 samples were started on July 25 and anticipated to be completed by September 1
  - HP-Al bond coat/CP-Al sprayed with N_2 should be completed by September 25
- Testing is being coordinated with Penn State, Pax River, Cherry Point, Westmoreland, L&M Machine Shop, TEC, and UTRC. December 2009 for most data!
- Demonstration at Cherry Point by the end of 2009
- Qualification of ASB and Demonstration at their site by the end of 2009
- Possibility that DSTO, Rosebank, and the Australian Navy might sign off on the process by the end of 2009

CGT Kinetics 4000 and K-Tech System

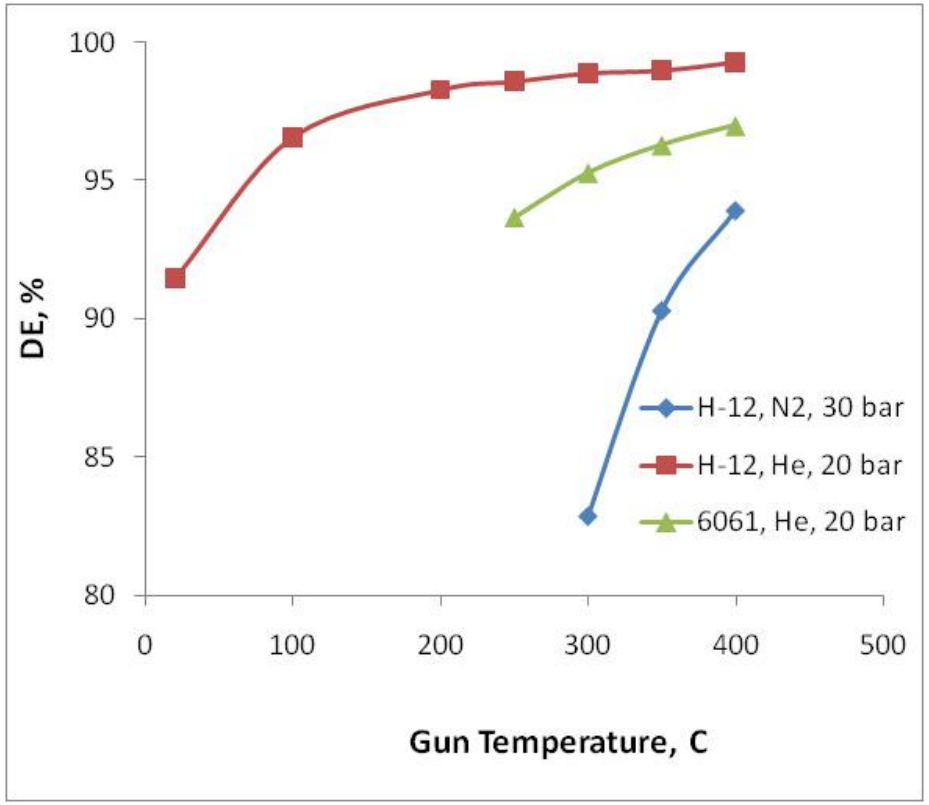
- 47 kW system Installed 6/2008 at APG (30 kW on floor and 17kW on gun)
- Only high pressure/high temperature C.S. system currently on the market
  - Temperatures up to 800°C (1472°F)
  - Pressures up to 40 bar (580 PSI)
- 17 kW system installation at NADEP-CP
  - Larger heat to be installed in late 2009
- Ktech System at ARL:
  - Temperature limited to 500°C
  - Pressures up to 35 bar (500 PSI)
  - 25 kW heater on floor
  - Heated powder gas feed

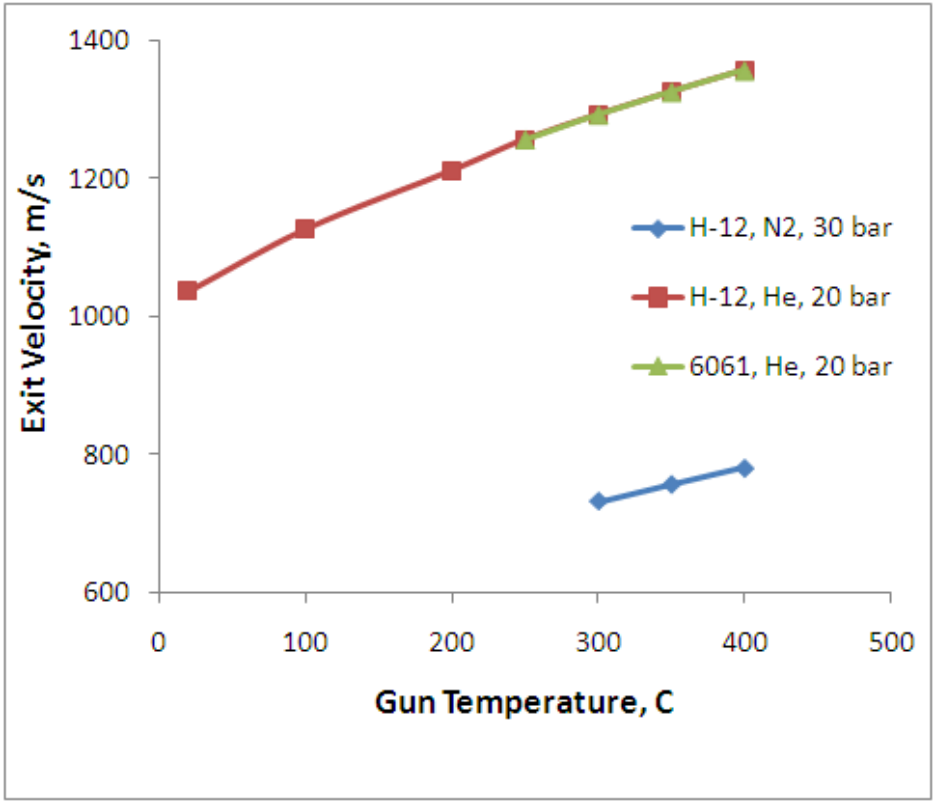




CGT 4000 Models

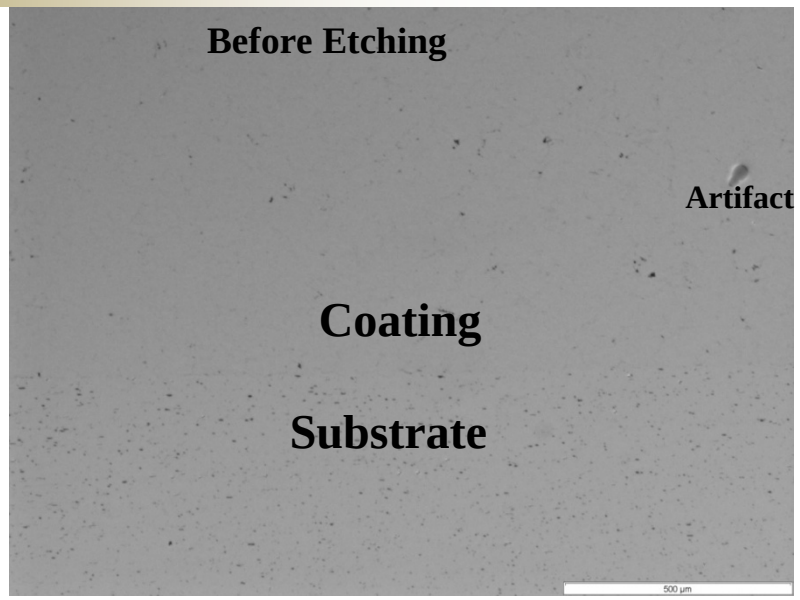
Modeled deposition efficiencies appear to be close to experimental values while the calculated velocities are well above the critical velocities for Al (~500 m/s)

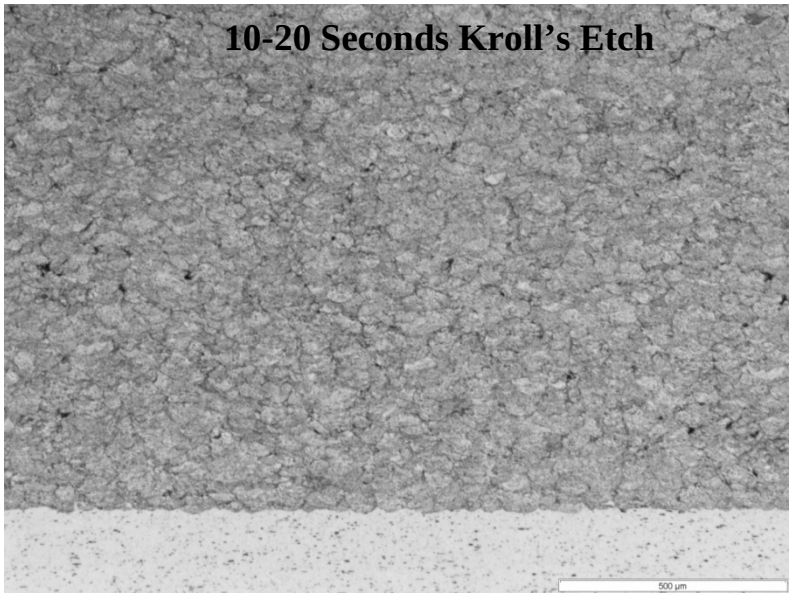




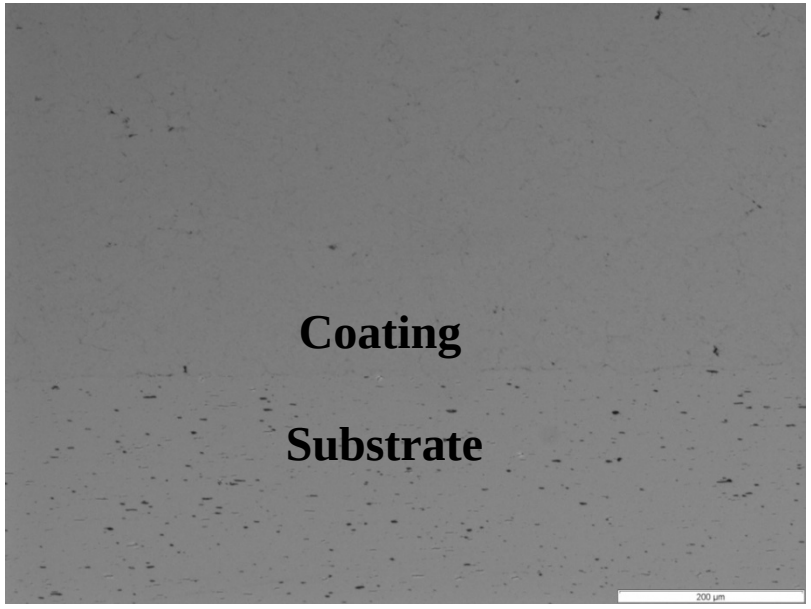
Valimet 6061 Cold Spray on 6061 Substrate: Optical Microscopy

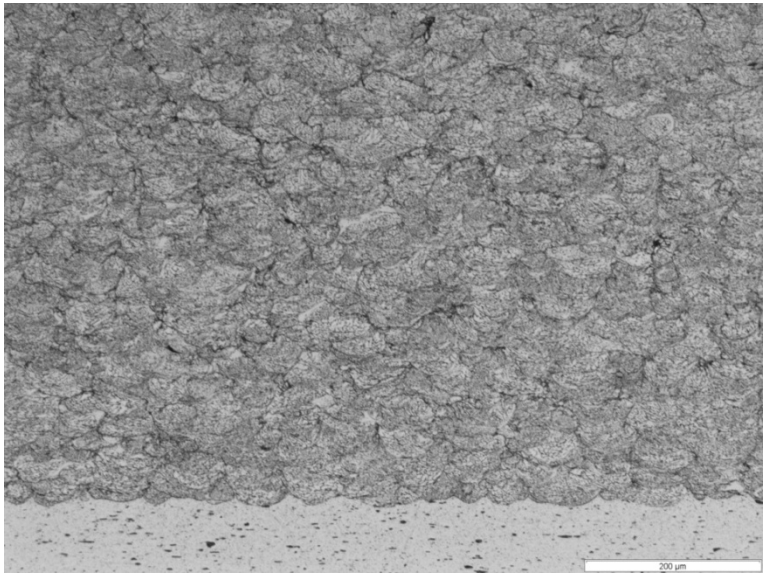
50X





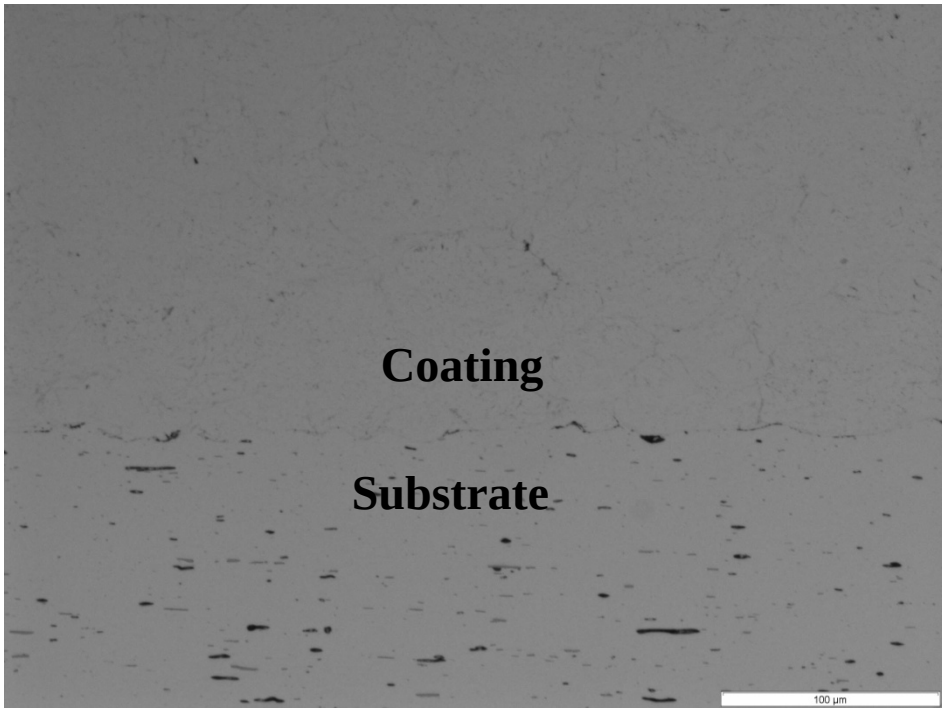
100X



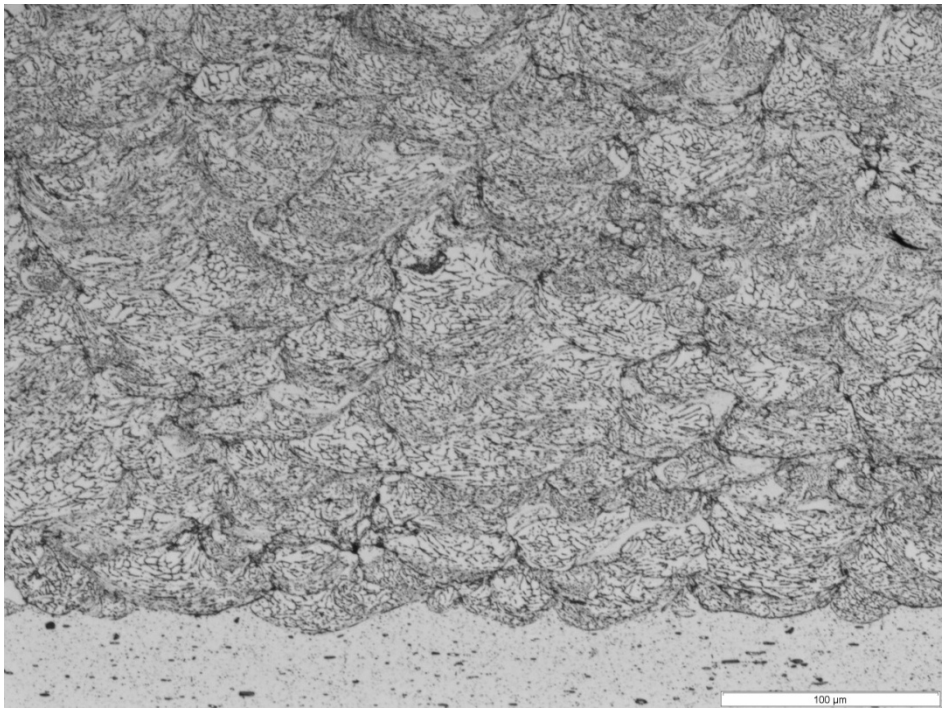


Valimet 6061 Cold Spray on 6061 Substrate: Optical Microscopy

Before Etching



10-20 Seconds Kroll's Etch



200X

Valimet H-12 CP-Al Cold Spray on 6061 Substrate: Optical Microscopy

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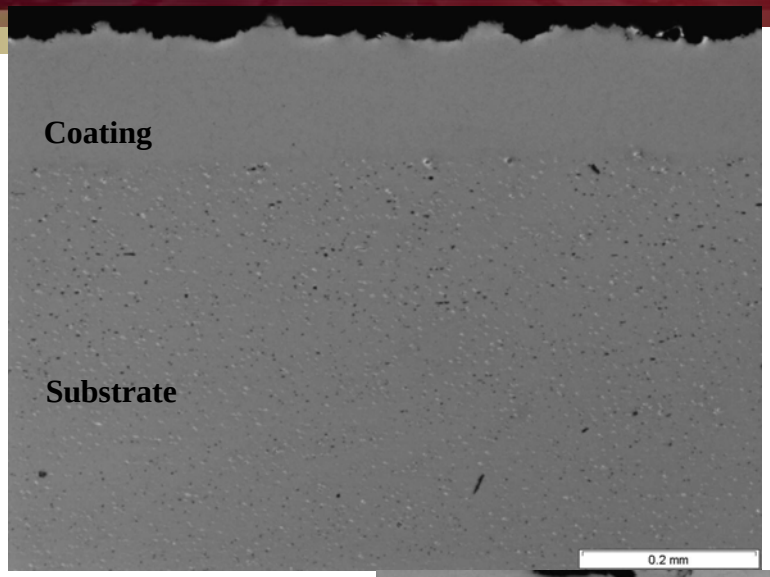

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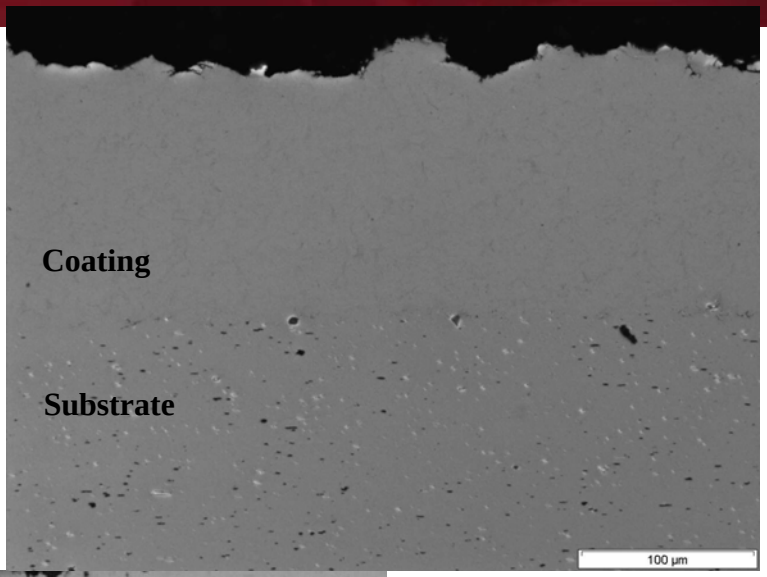

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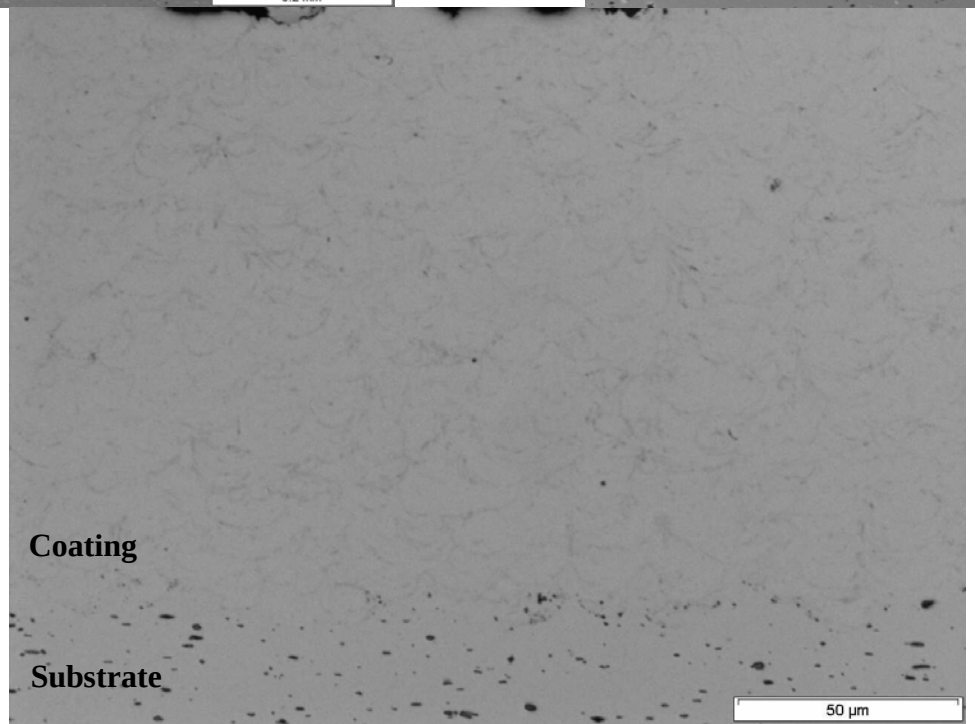
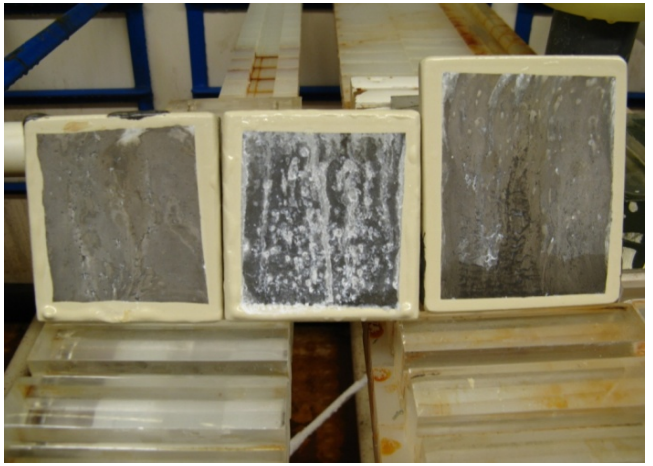


Technical Progress: Preliminary Kinetics 4000 data

- Improved D.E. from 34% to over 60% as compared to the K-Tech
- Adhesion values similar to K-Tech (10 KSI for CP-Al)
- Coating Densities >98.5% Theoretical Density for CP-Al with N_2

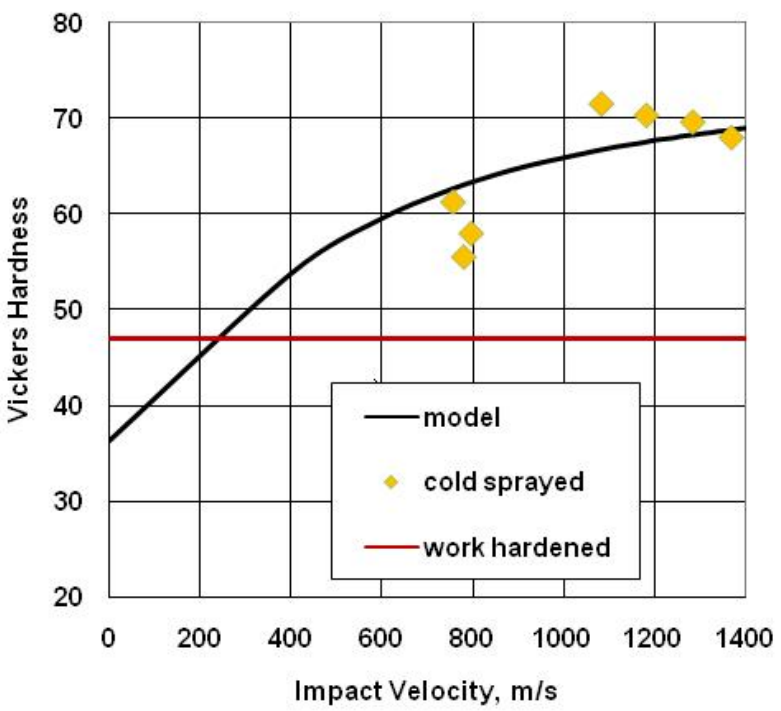
  >99.3% for 6061AA with He

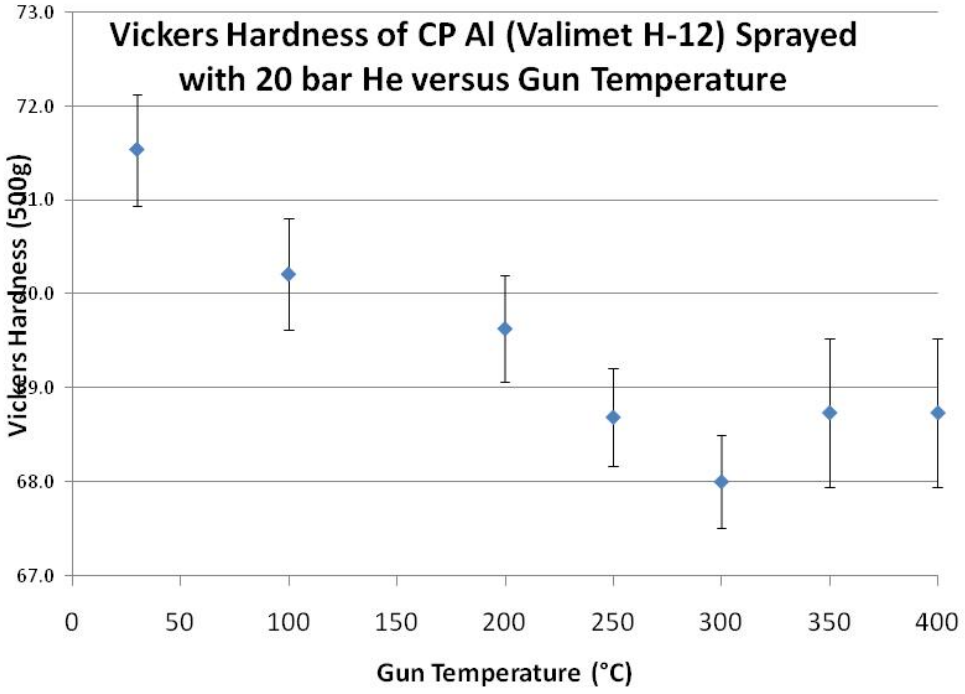
CP-Al Cold Spray Coatings entered Salt Fog on 3/4/09 ((~1/2 yr.)



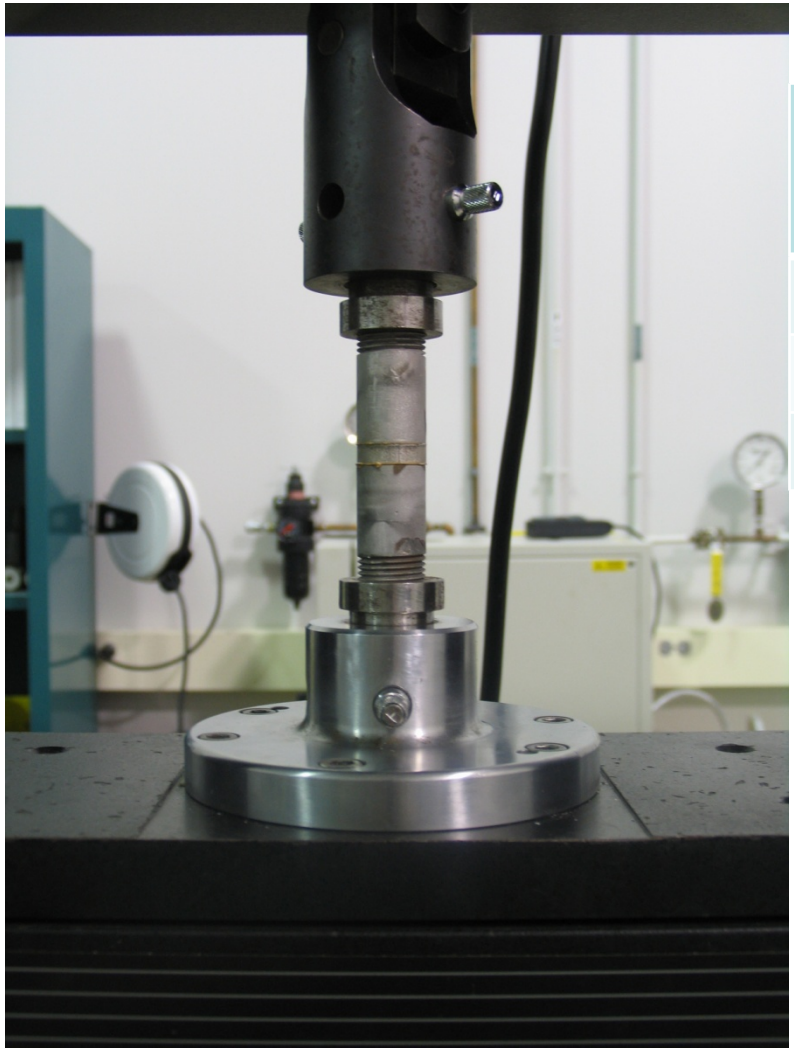
6061 Cold Spray Coatings entered Salt Fog on 3/9/09 (~1/2 yr.)

CP-Al Hardness





Bond Bar Adhesion (ASTM [illegible])



6061 Results:

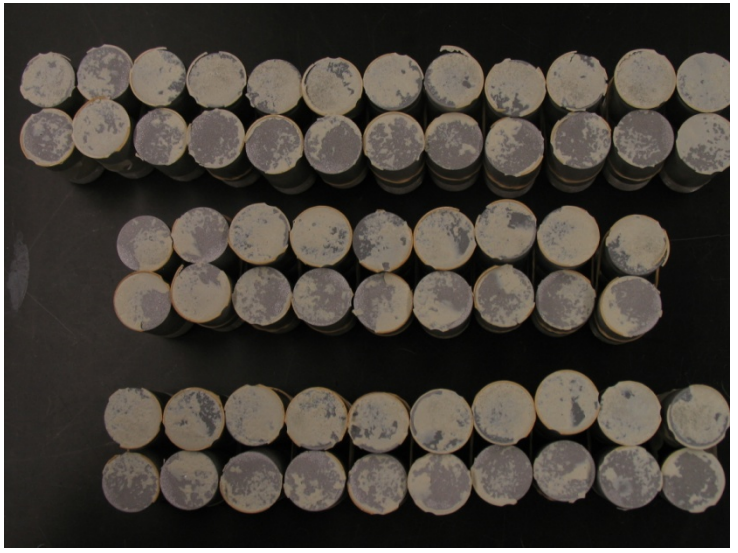
All Samples failed within the adhesive and not at the coating/substrate interface

Alloy	Average (ksi)	Stdev (ksi)	95% Confidence (ksi)
ZE41A-T5	11.1	0.8	10.5, 11.6
AZ91C-T6	10.8	1.1	9.9, 11.6
EV31-T6	11.2	0.7	10.8, 11.7

ZE41A-T5

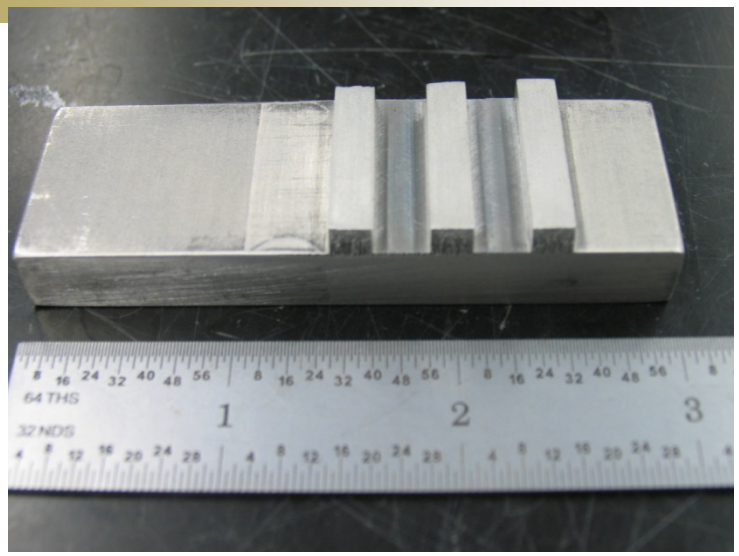
AZ91C-T6

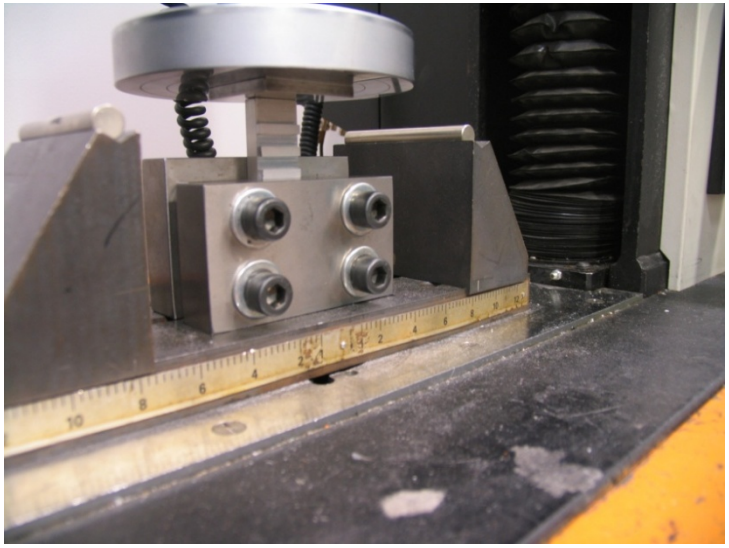
EV31-T6



CP-Al Preliminary ESTCP Data and DSTO Data show 10 ksi+

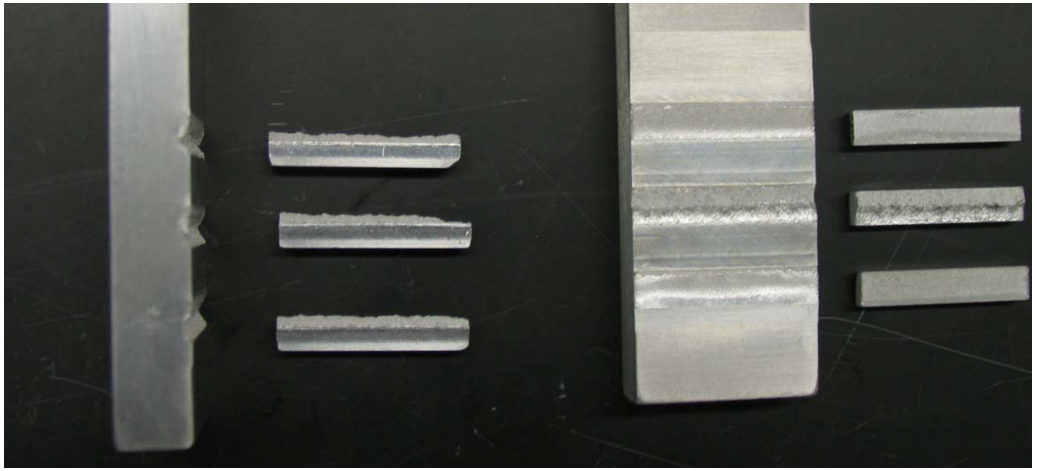
6061 Triple Lug Shear



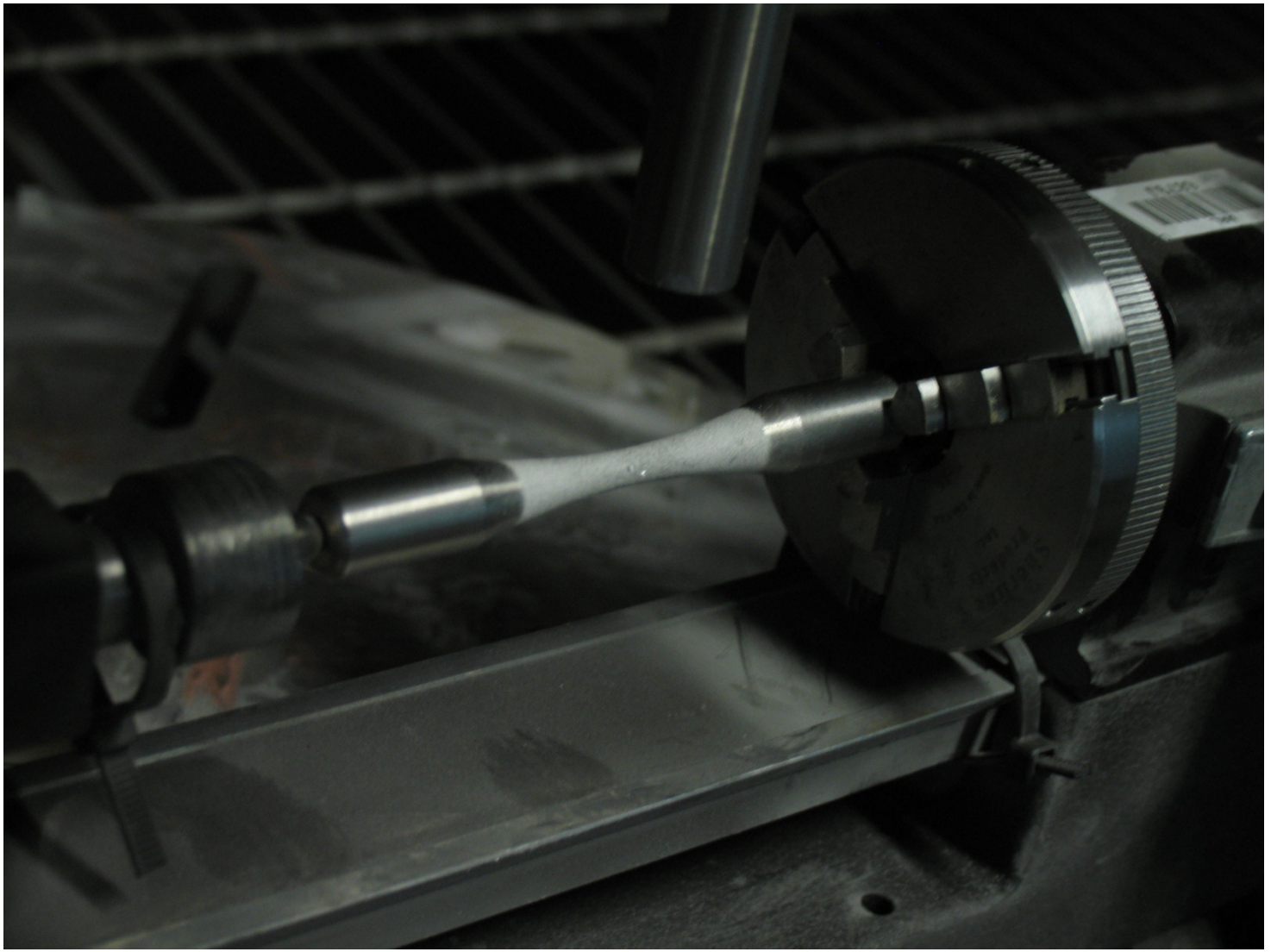


Alloy	Average (ksi)	Stdev (ksi)	95% Confidence (ksi)
ZE41A-T5	20.4	0.8	19.9, 20.8
AZ91C-T6	19.0	2.5	17.5, 20.5
EV31-T6	22.1	2.8	20.5, 23.7

- AZ91C-T6 and EV31-T6 failed with a relatively clean break at coating the interface
- 7 out of 12 ZE41A-T5 samples failed within the Mg

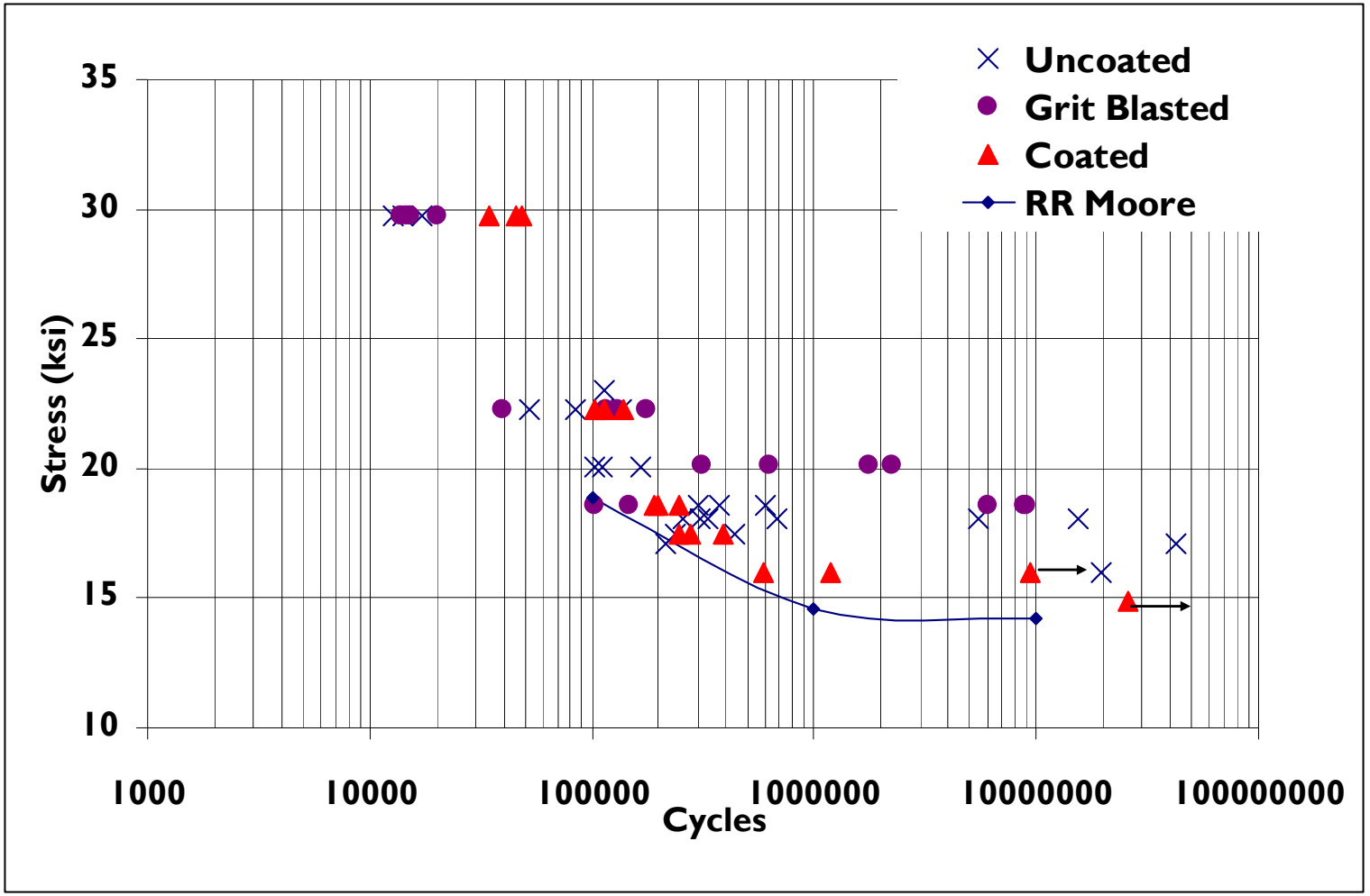


RCB Cold Spray Set-Up



Fatigue from DSTO Project

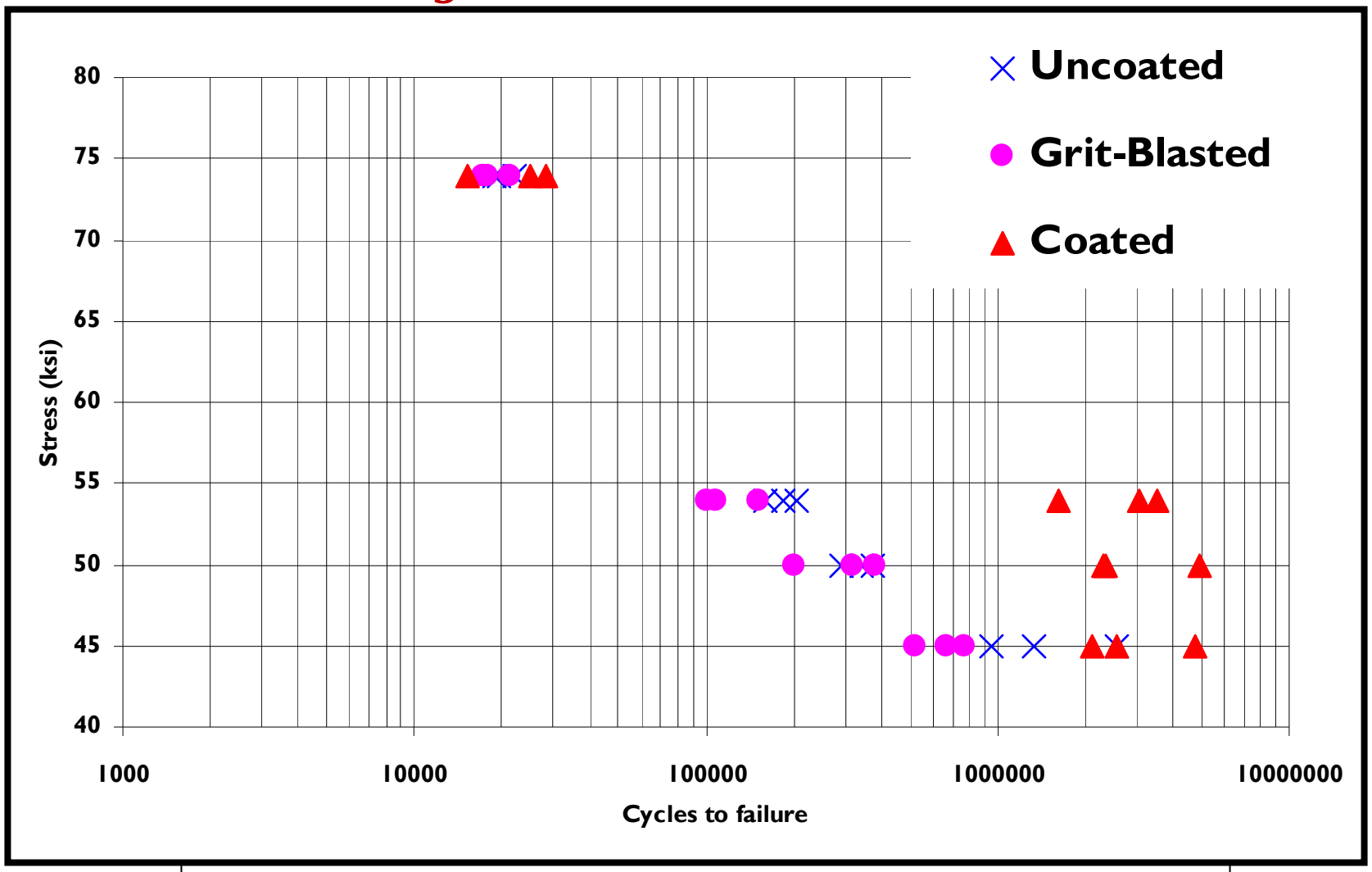
Fatigue Results – ZE41A-T5



Source – Australian Defense Science & Technology Organization

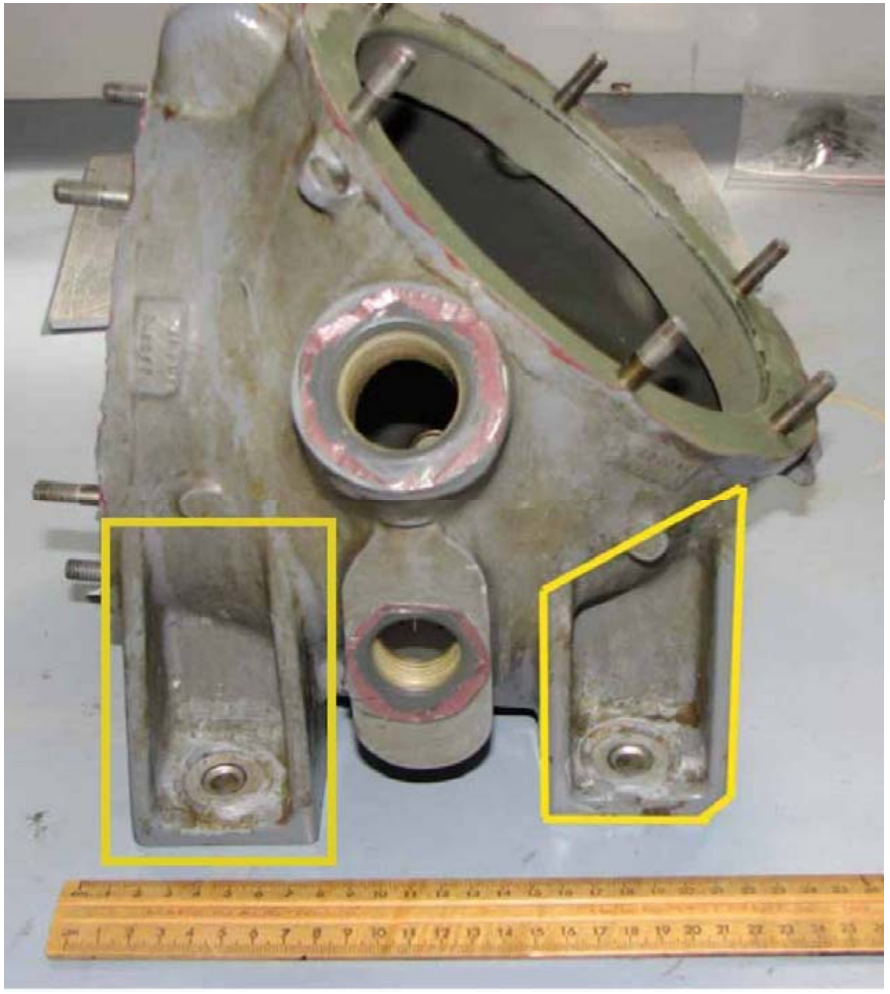
Fatigue from DSTO Project

Fatigue Results – AA7075-T651

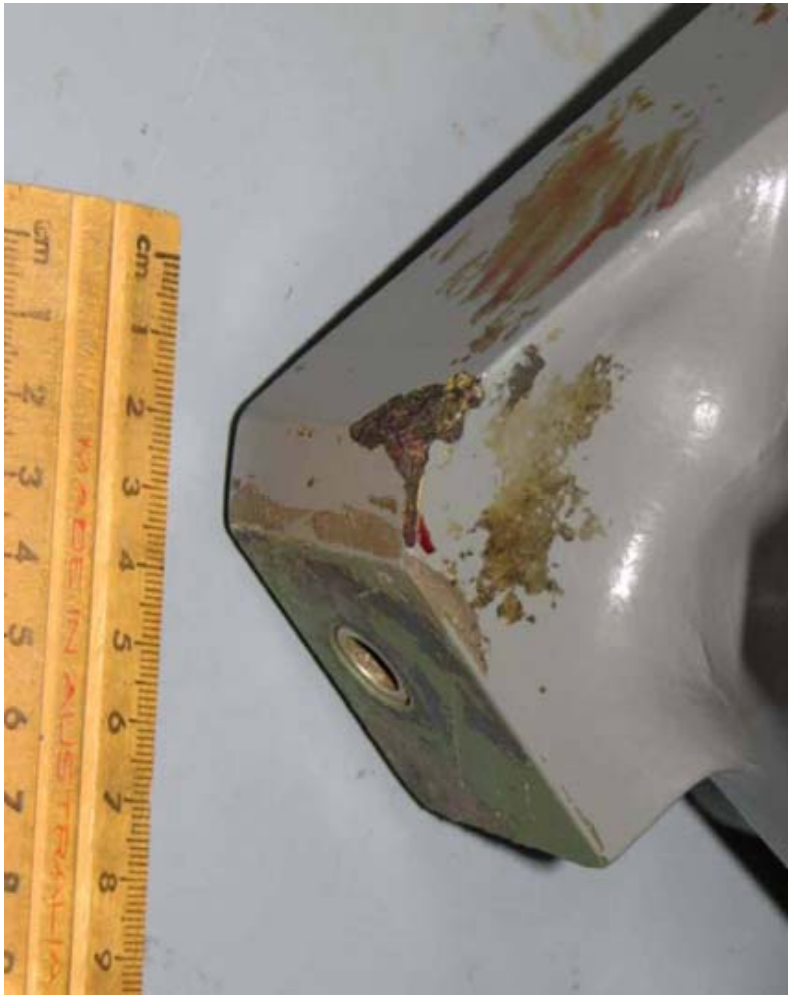


Source – Australian Defense Science & Technology Organization

Overview of 2008/Early 2009 Technical Progress: DSTO



Interior section of Intermediate Gearbox (IGB)

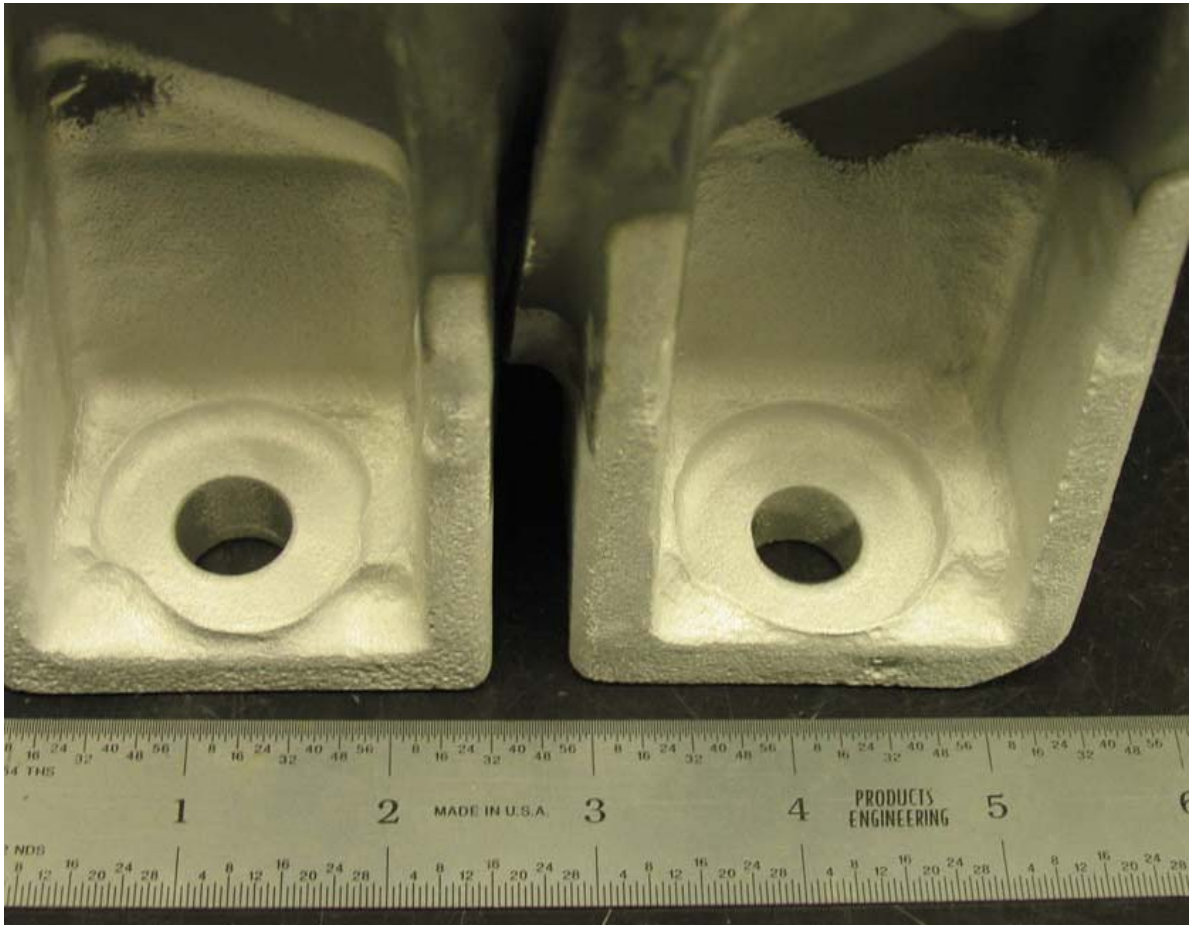


Exterior corroded area on one of the as-received IGB pads

Overview of 2008/Early 2009 Technical Progress: DSTO

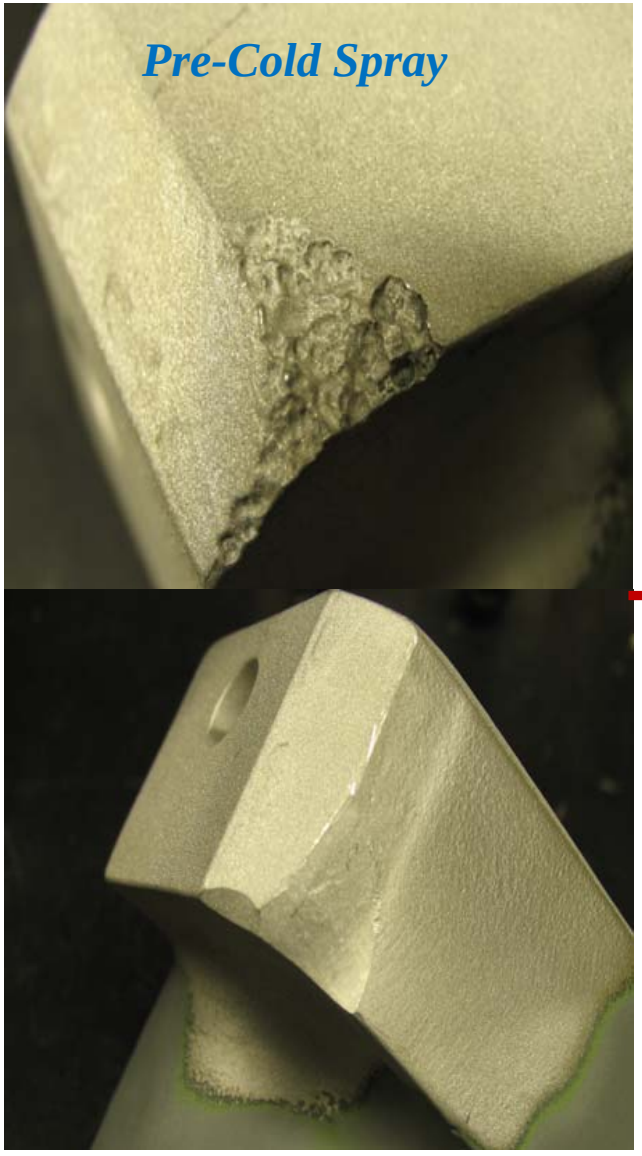
Interior section of IGB pads coated with CP-aluminum

Pre-Cold Spray

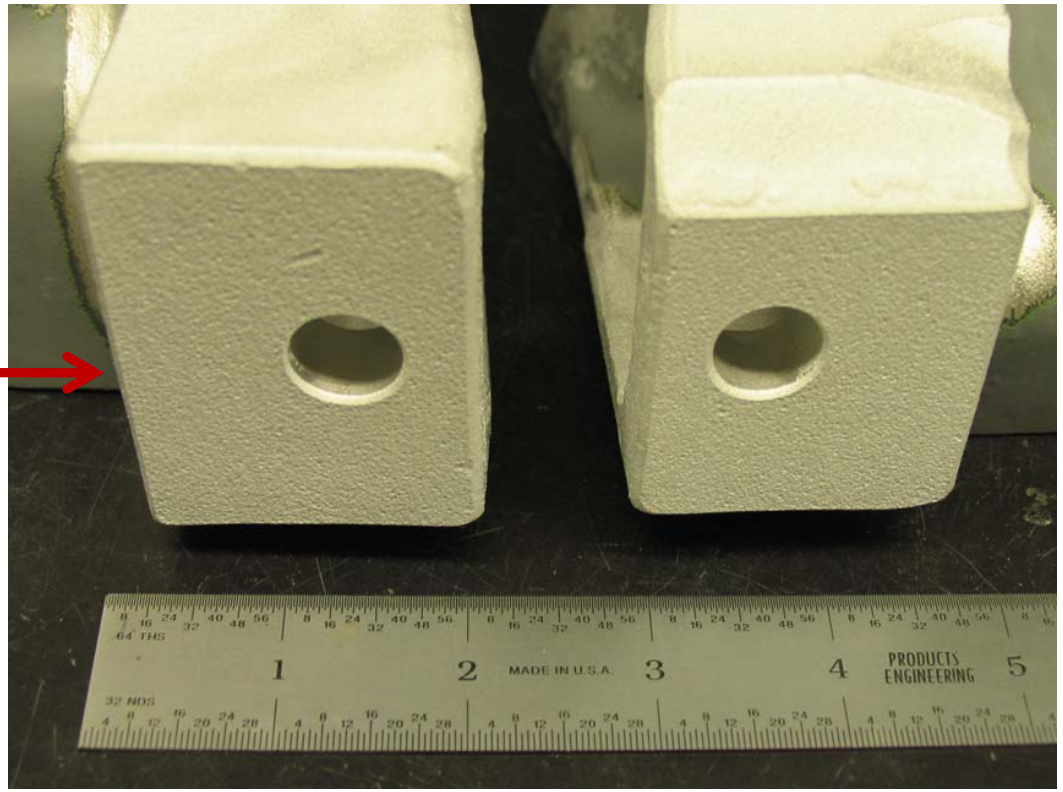


CP Al Cold Spray

Overview of 2008/Early 2009 Technical Progress: DSTO



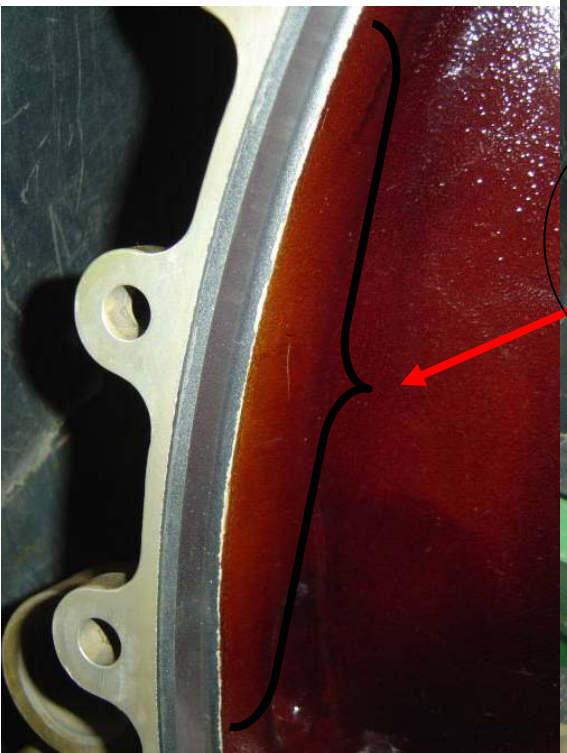
CP Al Cold Spray

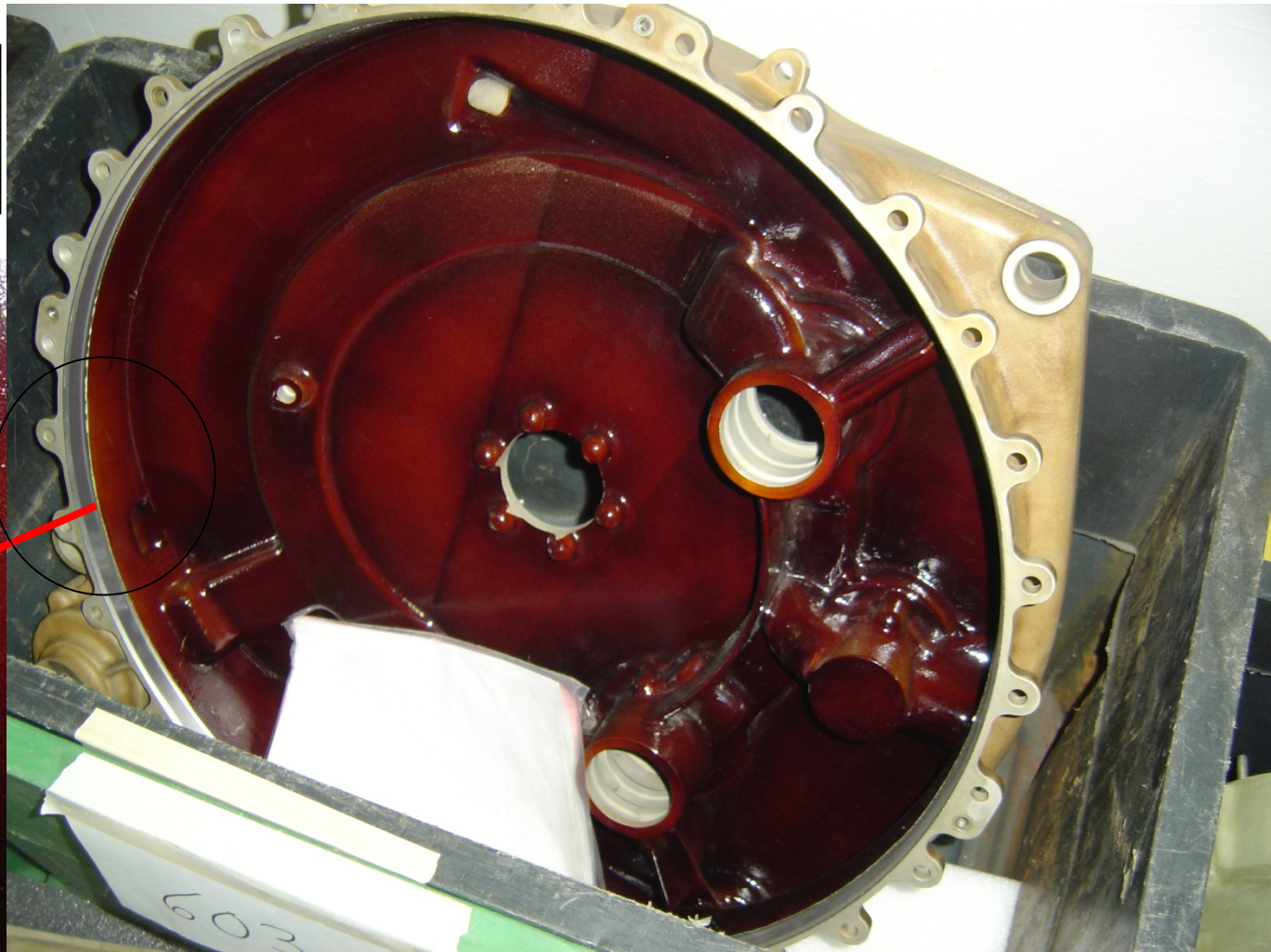


UH-60 Sump Assembly Main Module -Main Gearbox Repair

Repair Site:

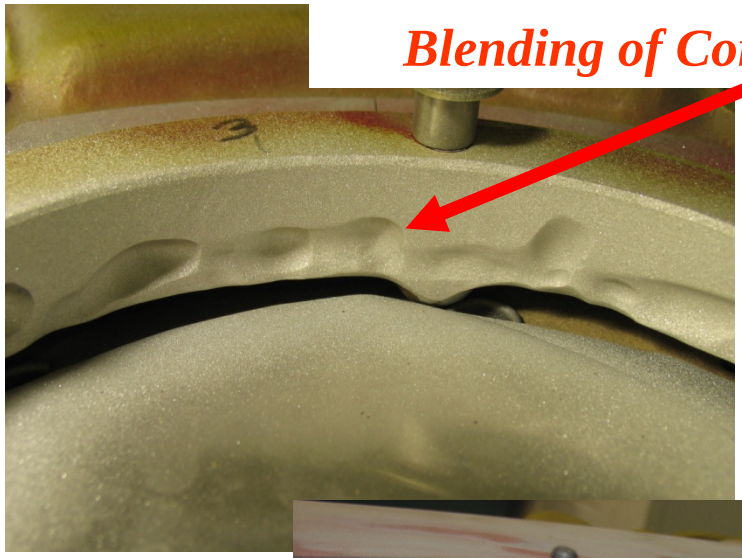
Rubber O-ring insert

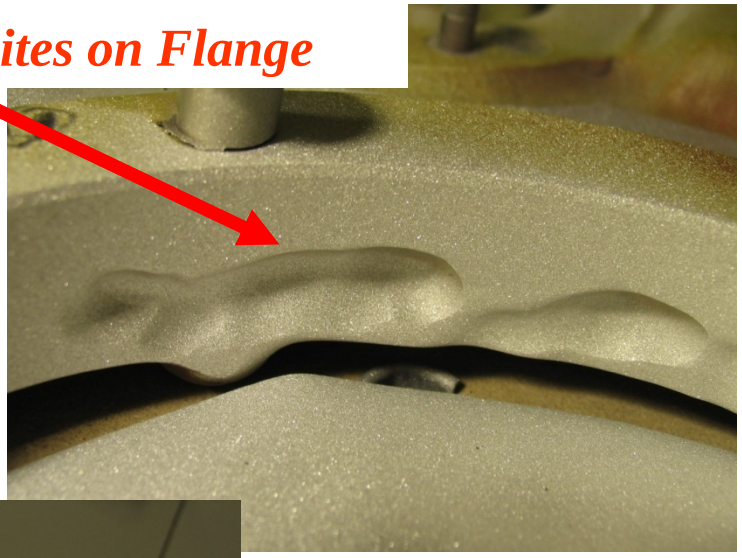


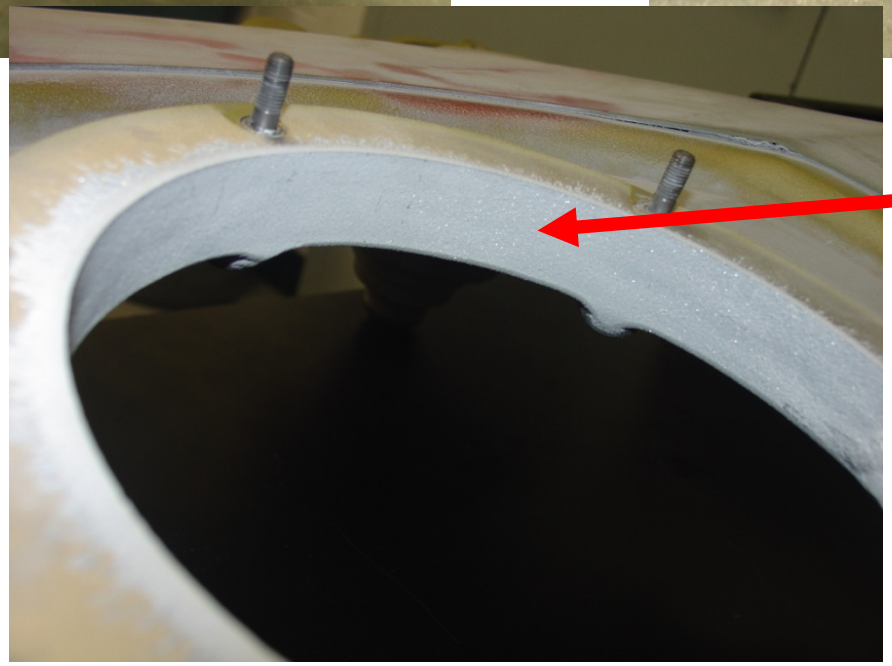


UH-60 Sump Assembly Main Module -Main Gearbox Repair

Blending of Corroded Sites on Flange







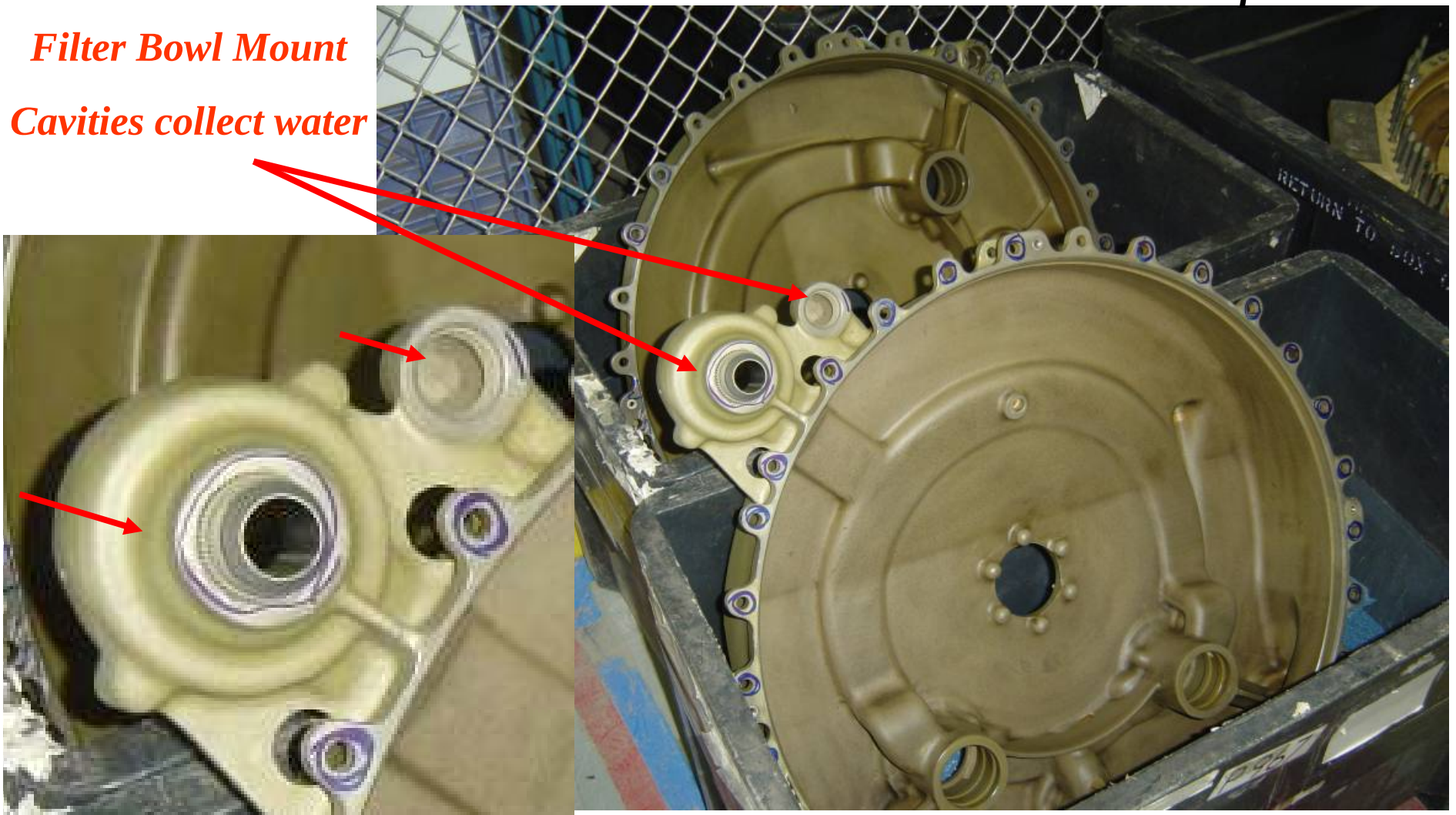
Cold Spray Repair of Inside Diameter of Flange

UH-60 Sump Assembly Main Module -Main Gearbox Repair

Repair Site:

Filter Bowl Mount

Cavities collect water



UH-60 Sump Assembly Main Module -Main Gearbox Repair

Summary

Cold Spray offers a cost effective and environmentally friendly method for repair and corrosion protection of Mg Components

- Hardness
  - ZE41A Magnesium alloy = 68 Vickers
  - Cold Spray CP-Al = 63 Vickers
  - 6061=105 Vickers
- Bond Strength
  - >6061 has >10,000 psi on ZE41, AZ91, and EV31 (CGT)
  - >6061 surpassed 15,000 PSI for Triple Lug Shear
  - >CP-Al/HP-Al has >=10,000 psi on ZE41 and AZ91 (K-Tech and CGT)
- RCB Fatigue Strength
  - Minimal effect on both 7075-T6 and ZE41A Magnesium Alloy
- Salt Fog Corrosion
  - >4000 hrs on CGT (on going) and 6000+ hrs for K-Tech